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Published in:
Applied Vegetation Science

DOI:
10.2307/1478886

Applied Vegetation Science 2: 95-106, 1999

Wetland restoration in Central Europe: aims and methods

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Abstract. Wetlands have always been of particular significance for mankind. While originally attractive as hunting grounds, they were later cultivated and modified from sinks into sources. Today, great efforts are being made to restore disturbed or destroyed wetland areas.

Different models and goals for wetland restoration exist. From a global point of view, reduction of climatically relevant trace gas emissions is relevant, especially in the case of fens. Regionally and locally, the creation of retention basins for water and compounds or the establishment of characteristic fen species and communities may have high priority. In order to avoid goal conflicts, nature development plans are required which consider not just the wetland to be restored, but the entire catchment area. Such plans should include spatially and temporally differentiated recommendations for implementation of restoration measures and a proper land use system. When it comes to defining concrete aims, the participation of local people should be encouraged.

Rewetting and oligotrophication are the most common approaches to boost biodiversity in fen ecosystems in Central and Western Europe. Rewetting includes both quantitative and qualitative aspects, requiring quantitative hydrological models and chemical analyses of the groundwater in the region. In addition, re-introduction of species is often necessary, at least in heavily fragmented cultural landscapes. Transfer of hay from donor areas to severely damaged, seed-depleted peatland to restore fen meadows, was successful. However, despite short-term successes, complete restoration of wetland areas requires a long period of time.

Keywords: Mire; Rewetting; Species introduction.

Introduction: The significance of wetlands for society

Wetland definitions are numerous and the terminology is often used inconsistently (Hofstetter 1983; Wheeler 1995). We welcome, therefore, the recent initiative of the International Mire Conservation Group (IMCG) to develop internationally acceptable definitions of the various wetland types according to clear criteria. Whatever the definition of wetland adopted, a crucial feature is periodic water saturation (surface water or ground water) in the rooting zone, leading to poor aeration and the prevalence of species adapted to such conditions (cf. Lugo 1990).

Wetlands have always been of particular significance for mankind (Dugan 1993). Three phases may be distinguished. At first, people used the abundance of fish and animals in wetlands; early settlements were preferentially established along the margins of river floodplains, large swamp or bog areas, or at river confluences. In many countries of Africa, Latin America and Asia, this dependence on wetlands is still evident. Even in C. Europe, it is easy to deduce the preference for wetland margins from the location of major cities.

A second phase started in the Middle Ages. In The Netherlands, Germany and Poland most wetlands were reclaimed by monks. At the end of the period of European absolutism with its conflicts new land was required for resettling. Drainage and cultivation increased enormously during the period of industrialism that followed. Water courses were regulated and swamps were drained in order to grow crops, establish meadows or to dug peat for fuel (e.g. Göttlich et al. 1993). Until the first half ot the 19th century there was little technical input in agricultural use. Wetlands were either grazed or shallow drained and used as litter meadows. Brook valleys were often artificially flooded to improve the fertility of the peatland (Krause & Balátová-Tulácková 1977). After the introduction of artificial fertilizers and the development of drainage techniques it became possible to cultivate mires on a large scale (e.g. Ganzert 1992). Wet-meadow communities, such as the *Caricion davallianae* and *Molinion*, have only remained in areas where remnants of the pre-industrial land use tradition have survived until now (e.g. in mountain areas with high precipitation and some sparsely populated areas in E. Europe). We can distinguish a gradient from (almost) undisturbed mires with active peat accumulation to fully degenerated peat deposits, reflecting the intensity of human use as well as moisture conditions (Fig. 1). Unfertilized *Molinion* meadows and fertilized *Calthion* meadows occupy the middle part of this gradient; they are more or less regularly mown and are richer in species than both undisturbed and fully cultivated fens. Fen meadows are still strongly influenced by calcareous groundwater, although the flow pattern of the prevailing hydrological system may have been drastically changed

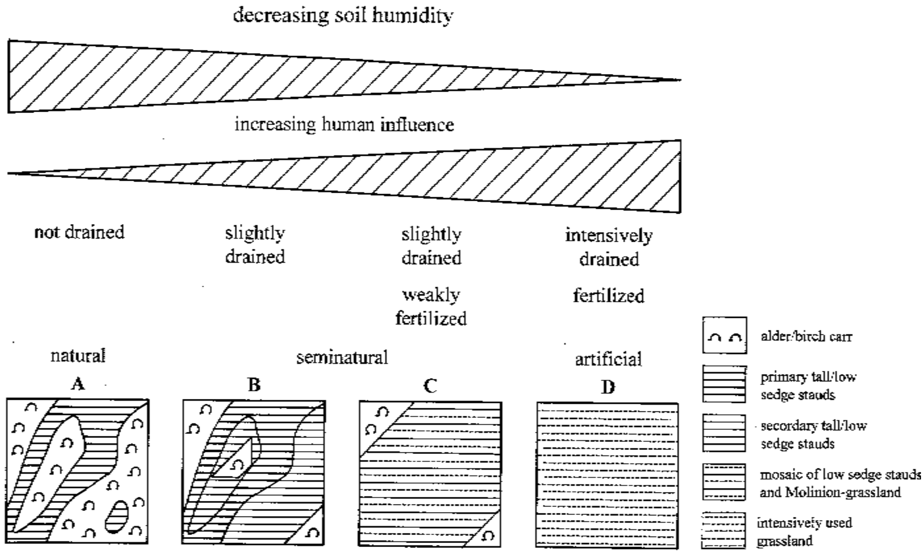

Fig. 1. Gradient of human influence in European fens with four phases characterized by five vegetation types.
A: Largely undisturbed fen;
B: Slightly drained fens used for grazing, mowing or litter collection;
C: Drained and slightly fertilized fen with *Calthion* grassland;
D: Heavily drained and fertilized fen.

by man (Boeye et al. 1994; van Diggelen 1998).

The third phase coincides with the increasing significance of nature conservation, as a reaction to the extraordinarily high loss of wetland areas and species diversity. This was already anticipated by more visionary scientists of the 19th century: J.H.Ch. Dau in 1829 and C.A. Weber in 1901; see Ant (1972). National and international conventions for the protection of remaining wetlands followed with increasing success. Knowledge on wetlands as functional ecosystems deepened and efforts towards their protection intensified (Klötzli 1991).

Today, these efforts have culminated in restoration concepts and measures, but not always with clear goals (Hobbs & Norton 1996; Young 1996). Whether the goal is the return to a more natural state (without human influence) or a historical (semi-natural) state depends on sociopolitical factors, which are practically always influenced by aesthetic/emotional models and ideals. The beauty of a flower-covered moist meadow or the historic-cultural significance of a particular species such as the stork plays a crucial role in the way most people experience nature. Many people in rural areas in particular, do not appreciate 'wilderness' as represented by natural wetlands, i.e. without human influence. In contrast to high mountain regions or coastal landscapes, most marshes, with their physically impenetrable, disorientating structure, have acquired deterrent names and appeal only to those who are more familiar with the ecological conditions involved. Models and goals for wetland development often start from the interaction between nature conservation, science and interest from society. These aims may in the end gain political support as the awareness grows that wetlands are becoming less suitable for modern agricultural production.

Aims and priority models for restoration

A development model for a wetland defines its potential natural state given the present state of knowledge. From a nature conservation point of view, it is the highest attainable goal of rehabilitation. However, the model does not consider temporal limitations or socio-economic restrictions, and is only adjusted when irreversible changes in the wetland environment have been assessed. Along this line of reasoning, it seems reasonable to base restoration prospects of disturbed or destroyed wetlands on its present (*status quo*) condition. On the other hand, socio-economic considerations and temporal restrictions limit the realization of a chosen restoration goal for a certain wetland or parts thereof. The evaluation of the sociopolitical interests may even include cost-benefit analyses.

A first step in the restoration of a wetland to a desired state, is the assessment of its future prospects. Such an assessment is related to both goal and present state of knowledge. The present state of more than 90% of all C. and W. European groundwater-fed mires (see e.g. Grosse-Brauckmann 1997) can be summarized as follows: peat soils which are intensively used for agriculture (sown grassland, permanent meadow/pasture, arable fields) are deeply drained and the original peat structure has been completely changed. Shrinking and peat loss through deflation and mineralization amount up to 2 cm per year. Consequences:

- Desiccation and degradation of meadows and pastures, spread of uneconomical weeds (Ellenberg 1952; Grootjans et al. 1985; Succow 1988): loss of sustainability in soil management.
- Release of up to 40 kg N_2O-N and up to 10 t CO_2-C per ha and yr, as well as of nitrate (Armentano & Menges

1986; Glenn et al. 1993; Nykänen et al. 1995; Velthof & Oenema 1994; Augustin et al. 1996; Wild & Pfadenhauer 1997; Flessa et al. 1998), with pollution of ground- and surface water: loss of nutrient retention capacity.

- Breakdown of the existing hydrological system into smaller subsystems (Wassen et al. 1996; van Diggelen et al. 1996), leading to loss of water retention capacity (accelerated water runoff in some areas and water shortage elsewhere). Without artificial surface water supply, this leads to increased water table fluctuations and associated changes in nutrient availability in fen areas (de Mars et al. 1996) or to increased acidification, particularly in areas with a large precipitation surplus (van Wirdum 1991; Spieksma et al. 1997).
- Loss of typical fen plant species and phytocoenoses due to mire cultivation, including the loss of seed banks (Pfadenhauer et al. 1991; Pfadenhauer & Maas 1987; Succow 1988; Poschlod 1995; Schopp-Guth 1997): loss of habitat function.

The impact of degraded fens on the environment is of supraregional and even global significance; the emission of airborne gases from peat deposits in Germany totals ca. 23 000 t N_2O-N and 6,7 $\times 10^6$ t CO_2-C/yr. or ca. 10 % and 1 %, respectively, of the quantities emitted by traffic and industry (Umweltbundesamt Berlin unpubl.). The decreased water retention capacity results in increased erosion (danger of land slides) in source areas of rivers and increased flooding in downstream areas situated hundreds of km from the upstream areas. Species losses always occur on a local scale, although this may occur over large areas. Based on the differences in spatial scale we may distinguish three different (hierarchical) targets.

First priority: abiotic target. Reduction of the emission of climatically relevant trace gases, avoidance of nitrate surpluses, boost the retention function of wetlands in water management (first priority from a supraregional and global point of view).

Second priority: biotic target. Promote the immigration and establishment of locally extinct wetland species in new suitable habitats.

Third priority: land use target. Stimulate sustainable use of wetland soils by promoting a water management that protects peat soil and only permits a less intensive agricultural use of meadows and pastures (local and regional land use target).

While most scientists, nature conservationists and associated parties have now more or less accepted the general formulation of these targets, a considerable potential for conflict still exists in defining specific aims for nature development. These aims are far more detailed and require spatial, temporal and socio-economic coordination. Several areas of conflict can be defined.

Conflicting aims

Once aims have been defined and the degraded peat deposit has been taken as the initial state, we may select any combination of wet meadows, tall-sedge reeds or even fen carrs as the target, assuming that the necessary rewetting is possible. Some might argue that rewetting degraded fens promotes methane emission which could compensate the reduction of CO_2- and N_2O-emission. But even high methane emissions (up to 300 kg ha^{-1}yr^{-1} for N. Germany; unpubl., courtesy Bodentechnologisches Inst., Bremen) is less important: the global warming potential is much lower than that of N_2O (Anon. 1992).

In the case of a fen meadow, rewetting in winter will only partly fulfil the abiotic model; the loss of peat cannot be completely prevented. In the case of the tall sedge reed, it is perhaps necessary to renounce most of the biotic model (regarding the goal of botanical species conservation) since rewetting of previously deeply drained and intensively used (fertilized) peats promotes a high-productive vegetation type (Rosenthal 1992; Hellberg 1995). Consequently reed- or sedge stands will be very species-poor. Aim conflicts become still more acute when different target species require different conditions.

Temporal complications

Wetland biocenoses which have originated from long-term traditional management – which is no longer practised – often serve as a model for restoration policy. Such a historically orientated model is problematic for two reasons: First, it is not sure whether such biocenoses can be sustained under future socio-economic circumstances: if not, the protected or even re-established biocenoses then become cultural monuments, maintained at high costs. Second, we are still not able to predict the future vegetation and peat development of rewetted mires. Stochastic events regarding flooding and species migration as well as climatic changes hinder the predictability of restoration results in the long run. At best we know the potential vegetation development, given the geological and climatic conditions of the area. The actual hydrological and pedological conditions, however, will be severely altered after rewetting (van Diggelen et al. 1994).

Many present-day grassland species are young from an evolutionarily viewpoint, and have arisen from hybrids, which escaped infertility by doubling their chromosome numbers (Grant 1971; Urbanska 1987). Many other grassland species have flourished in forests and marshes or even mountain areas before man started to expand the natural grasslands. Thus, species may re-establish in combinations different from the ones registered in macro-remains of the peat (Tallis 1991). Attempts to restore semi-natural plant communities may result in the development of completely new plant combinations which may considerably deviate from the remnants still existing in the old agricultural landscape, even if we succeed in restoring most of the abiotic environmental conditions. Therefore, temporal aspects of restoration impose severe problems for phytosociology regarding the fixed composition of a plant community (Grootjans et al. 1996). Syntaxonomic units are therefore unsuitable for predicting future vegetation developments.

Spatial complications

Development measures in wetlands are often restricted in terms of their spatial implementation (Fig. 2). In practice, effective rewetting is applied only in small parts of the mire, due to a restricted availability of land or in order to avoid conflicts with adjoining land owners (A). Neither the entire wetland ecosystem (B), as a more or less closed system, nor the catchment area (C) have hardly ever been considered, although the significance of restoring hydrological systems for a successful restoration process has been repeatedly emphasized (Pfadenhauer & Krüger 1991; Grootjans et al. 1993; van Diggelen et al. 1995; Wheeler et al. 1995; Schopp-Guth 1999). Dissolved substances and sometimes large amounts of sediments are brought in with water from surrounding areas. Such potential effects on the restoration processes need to be considered before aims are set and measures carried out. Often large sections of land are needed to counter unwanted and unforeseen external influences in restoration areas. Buffer zones must be incorporated when a higher water quality is required for the development of meso- to oligotrophic plant communities. The Wurzacher Ried in southern Germany is an example of such a spatially integrated development plan. This mire complex has gained the status of European Nature Reserve and consequently must be protected against nutrient and sediment immissions from the rest of the catchment. Therefore, a less intensive agricultural use and the installation of reeds as biological filter systems are being scheduled (Krüger & Pfadenhauer 1991; Pfadenhauer 1998a).

Even when spatially integrating restoration planning is carried out, its implementation is often restricted, not because of lack of knowledge on the functional relationships in the landscape, but due to fragmentation of landownership. This is the main reason why so many restoration projects fail. Planning is mostly insufficiently incorporated in adjoining areas. Consequently only parts of destroyed wetlands could be rewetted, often with disappointing and inadequate results (van Duren et al. 1997a,b, 1998).

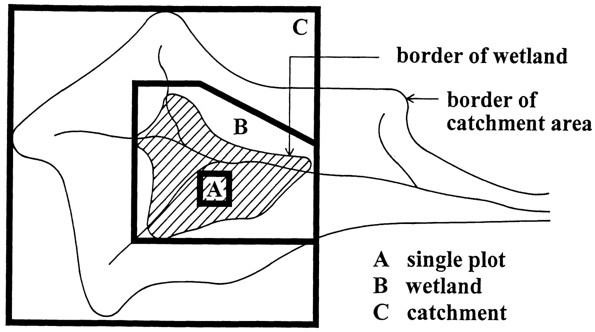

Fig. 2. Spatial complications of a restoration scheme: different planning levels in wetlands.

Socio-economic complications

The fragmentation of landownership has economic and legal consequences. Most Central European peatlands are still more or less intensively used by farmers, who are not normally interested in reducing land use intensity nor in withdrawing from fields destined to be rewetted. Under the present socio-economic conditions, peat areas are agriculturally disadvantageous areas (Zeitz et al. 1997). Supportive subventions to combat unemployment here should consider environmental aspects as well; at least peat-protecting utilization should be promoted. In practise this means that intensive farming with crop rotation is banned from peat areas and less intensive use of permanent grassland is promoted. Unfortunately, political moves in this direction are lacking. Scientists, however, have repeatedly aroused public awareness on this matter by pointing to the huge airborne nitrogen emissions from intensively used (fen) peat areas (Pfadenhauer et al. 1991; Succow 1988, 1998). It is, therefore, important to identify alternative land use scenarios for the future which combine wetland utilization with wetland conservation. Two model projects are presented here.

Growing of raw materials in rewetted peatlands

Severely degraded wetland areas without any wetland species worth protecting are very suitable for the cultivation of highly productive reed plants, such as *Phragmites australis*, at least when permanent flooding is possible (Wichtmann & Koppisch 1998). The stalks can be used for thatched roofs, as supplementary material in the building industry and as 'energy reeds' (Björk & Granéli 1978). The shoots and leaves of *Typha* spp. are rich in aerenchyma tissue and are excellent for the manufacturing of insulating materials. Harvesting can be carried out when the wetland is frozen. Such a cultivation of industrially usable plants combines, in an ideal way, wetland utility as an alternative for farmers with several aspects of wetland conservation: (1) purification of nutrient-rich water from the catchment area, (2) retention of floodwater over a considerable time, (3) reduction of trace gas and nitrogen emissions, (4) feeding ground for waders and other wetland birds.

Extensive pasturing for the preservation of wet meadow species

After World War II, the need for bedding materials in stables has decreased drastically due to intensification of land use on the one hand and to mechanization of livestock stables on the other. This has led to a dramatic decline in species-rich litter meadow communities of the *Molinion* and *Caricion davallianae*. In Central Europe, litter meadows that are still used in the traditional way, only occur in substantial numbers along the northern edge of the alps (Pfadenhauer 1989). Setting aside of these meadows causes an uncontrollable invasion by *Phragmites australis* or other tall-growing eutraphent species (Briemle & Ellenberg 1994). Plant growth is promoted by a certain auto-eutrophication effect (Klötzli 1979, 1986; Gigon & Bocherens 1985), and increased competition for light decreases the species diversity.

In areas where traditional use is no longer possible, two alternatives remain: (1) management by nature conservation organizations including ex-farmers and (2) introduction of extensive-grazing systems. The first option requires much public spending and leads to highly specialized nature management, using equipment designed to mow extensive wet areas with little man power. The second option implies extensive grazing with light cattle breeds or with young cattle. This may represent a low-budget but viable alternative for the preservation of species-rich grasslands and is, in fact, an imitation of the former grazing system prior to the use of grasslands as litter meadow. The present direct marketing lines to large cities will certainly permit high earnings from beef production in natural areas.

Grazing, however, changes the overall colourful appearance of the meadows. For this reason some nature conservationists object to this practice. Cattle prefer dry places within a wetland leading to a rapid growth of tall herbs in the wet areas (Bakker & Grootjans 1991). However, it has not been proven that these changes in the relative abundance of species lead to rapid extinction of species in the area as a whole, at least not in the large mires in the northern prealps where extensive grazing systems exist over centuries in some places (Radlmair & Laußmann 1997; Pfadenhauer unpubl.). In this way the interests of the farmers can be promoted without much harm to most endangered meadow species. Extensive grazing offers an important strategy for nature conservation.

Restoration management plans: possibilities for rewetting and increasing species diversity

Restoration management plans are necessary in any approach which is aware of the conflicts pointed out in the previous section while attempting to overcome conflicting views. This is particularly important for cultural landscapes, where changes are always registered and judged against the background of the personal experiences of every observer. This may lead to considerable problems of acceptance, in particular in the case of mire restoration, since local people often consider themselves to be the descendants of cultivation-orientated mire pioneers.

Developmental plans should be very simple, while remaining logically sound. In the case of highly degraded fens in northeastern Germany, we have used simple criteria to select suitable areas for restoration (Pfadenhauer 1995; Pfadenhauer & Klötzli 1996): (1) fen depth, (2) rewetting potential and (3) presence of suitable target species. Fen depth has been chosen since we assumed that most of the organic material will soon be lost anyway at peat depths of less than 1m. The rewetting potential is chosen as a criterion, because one has to be sure that sufficient water is available in the area to allow permanent flooding and the function of a wetland as a sink can be restored. In areas such as in East Germany and certain parts of Poland with a large precipitation deficit in summer, an assessment of rewetting potential is particularly important and must include the entire catchment area of the wetland to be restored. The third criterion, the presence of target species, is more relevant when areas cannot be rewetted sufficiently. In that case the presence of characteristic fen- or fen meadow species is essential for carrying out a more flexible plan, in which several development goals must be pursued simultaneously. Implementation may occur in different subareas or even in different time periods. It may take some time before the site conditions of the restoration area meet the requirements of the target species. In such cases, temporary solutions must be found and linked to existing or new land use systems.

Numerous restoration attempts have been carried out in recent years to implement models within the scope of a developmental plan (Klötzli 1991; Wheeler & al. 1995; Pfadenhauer & Klötzli 1996; Brülisauer & Klötzli 1998; Pfadenhauer 1998b; Schopp-Guth 1999). Measures taken are diverse in their conception, execution and combination, because they had to be adapted to the individual wetlands (Beltman et al. 1995). What they have in common is a basic pattern of rewetting and increasing species diversity; their success may be measured as the difference between target state and status quo, and how soon the target state has been reached.

Rewetting

Without an additional influx of water with an ionic composition required for the survival of characteristic wetland species, wetland restoration is impossible. The restoration of species-rich *Calthion* and *Molinion* communities is relatively easy when the hydrological conditions have not been severely disturbed (Grootjans & van Diggelen 1998) and if relic populations or seed banks are still present (Bakker 1989; Bakker et al. 1996; Poschlod et al. 1998). Blocking ditches or drainage systems is often sufficient (e.g. Jansen et al. 1996); in many large fens the porosity of the peat body is still sufficient for a subsequent rise in the water table. This may be seen as a repair of earlier impacts (Wheeler 1995).

In severely degraded wetlands the situation is entirely different (van Diggelen 1998). Here, all characteristic species and functions of a wetland have been lost. If the wetland must be re-established this may be considered as rebuilding (Wheeler 1995). Such a situation is repeatedly encountered in Central Europe. Two examples may illustrate this:

Restoration attempts in a south German cut-over bog showed that, after flooding, re-establishment of ombrotrophic bog species such as *Sphagnum magellanicum* and *S. capillifolium* failed because the blockage of drainage ditches was insufficient to initiate *Sphagnum* growth on the dried and shrunken *Eriophorum-Sphagnum* peat. The very acid and nutrient poor mire water reaching the surface after ditch blocking had to be fertilized to promote any plant growth (Sliva et al. 1997). The result was a floating mat formed by minerotrophic *Sphagna* which eventually develop into a new bog expanse. Peat pits extending as far down as the mineral groundwater, regenerate in an analogous fashion, via various topogenous and transitional succession stages, to an ombrogenous bog (Pfadenhauer & Kinberger 1985; Poschlod 1990). Thus the bog is rebuilt from below (Fig. 3).

The situation in the severly degraded fens in Central Europe is very similar (Fig. 4). Particularly terrestrialization fens have shallow peat bodies underlain by large gyttja layers which have a high resistance to water flow. Due to deep drainage the horizontal saturated water permeability of the shallow peat layer has also become very low (Hennings 1996). A consequence is that the ground water level cannot reach the fen surface any more by mere ditch blocking. Effective rewetting leading to peat accumulation can only be accomplished by flooding (Hennings 1996; Heidt 1998). This additional water has to be brought in from other areas. Since the East German fens occasionally may suffer the consequences of a large precipitation deficit during the summer, it is important to store large quantities of water in the winter by setting dams as high as possible even at the risk of widespread flooding (Dietrich et al. 1996). Flooding in summer suppresses emissions of N_2O and CO_2, in particular because it temporarily promotes CH_4 (Blankenburg pers. comm.; Augustin et al. 1996). The additional water is mostly loaded with nutrients and sediments. But depositing into the rewetted mire is not a problem; the mire resumes its function as a nutrient sink. The vegetation reflects this situation and consists of highly productive reeds and large sedges.

Why introduction of species?

There is no doubt that vegetation plays a key role during restoration processes in mires. At least the ecological function of the upper peat layer depends on species composition. So it is essential to establish the relevant species as soon as possible. Many characteristic mire and meadow species are hardly capable of seed

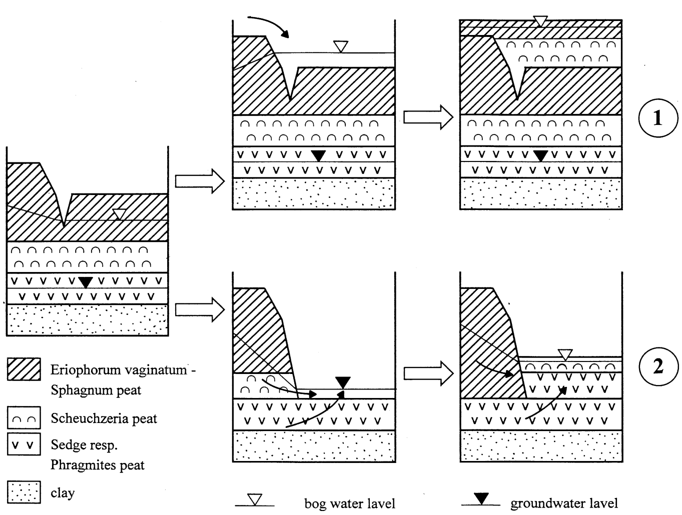

Fig. 3. Scheme of rebuilding drained raised bogs in S. Germany. 1: wetting by flooding, fertilization; 2: wetting by peat extraction, influence of groundwater. Arrows indicate incoming water.

dispersal over large distances, at least under the present conditions of the Central European cultural landscape (Bakker et al. 1996; Kapfer 1997; Poschlod et al. 1997). Regular flooding with surface water, which is probably the most important dispersal agent for many mire species (Cappers 1994; Danvid & Nilsson 1997) is nowadays largely prevented by roads, embankments and all other obstacles that prevent flooding. Many wetland species are well-adapted to dispersal by water; the seeds can float on the water for quite some time and they can survive for several weeks under wet conditions (Bonn & Poschlod 1998). Furthermore, donor areas for diaspores have become very scarce or cannot be reached by flood water. Hence, even with regular flooding adequate seed transport to many restoration sites might not be expected. Only wetland plants with effective wind dispersal like *Typha* and *Eriophorum* species or with seed transport by waders and ducks (like many species of the *Nanocyperion* communities) are present almost everywhere and immigrate rapidly (Poschlod et al. 1996).

In addition to the immigration of species from outside, activation of the seed bank is another possibility to re-establish a plant population. Many wetland species, in particular the eutraphent and hydrochorous ones, develop a persistent seed reserve (Van der Valk & Verhoeven 1988; Schopp-Guth et al. 1994). Regular ploughing of sown grassland and arable land brings the seeds to the surface and interrupts their darkness-induced dormancy; they germinate, only to be removed during subsequent cultivation. The seed reserve thus becomes ever more depleted. Many species of mesotrophic fen meadows, however, have a short-lived seed bank (Thompson et al. 1997; Bekker et al. 1997). Their seeds cannot survive over longer periods of intensive farming. So the soils of most degraded fens hardly contain a sufficient number of viable seeds of the former wetland vegetation to serve as restoration potential (Pfadenhauer & Maas 1987; Schopp-Guth 1997; Vegelin et al. 1997). An analysis of the seed bank prior to restoration measures can therefore be very helpful in assessing the regeneration potential of degraded fen areas.

It is an important prerequisite for the success of a restoration project that site conditions meet the biological requirements of the target species. Knowledge of the demographic behaviour and key-ecological factors for these species can be essential (Roelofs et al. 1996), even the presence of soil mycorrhizal fungi may be important in wetlands (Turner & Friese 1998; Cooke & Lefor 1998). Although we can only guess the crucial factors for species establishment in many types of ecosystems, the relevant processes for the restoration of *Molinion* meadows are well known (Kapfer 1988, 1997; Egloff 1986; Bakker 1989; Rosenthal 1992; De Mars 1997; Biewer 1997): Firstly, the nutrient levels of fertilized wetland sites must be depleted through mowing and removal of the hay, without further fertilization. The aim is to reduce crop yield to a maximum level of ca. 4t$ha^{-1}yr^{-1}$. Below this threshold level, the open and semi-shading structure of this plant cover is suitable for the germination and development of many wet meadow species.

The desired species are mostly small hemicryptophytes with low competitive ability; their seeds are subjected to an innate dormancy which can be ended by temperature fluctuations of the diurnal rhythm (Maas 1989; Patzelt & Pfadenhauer 1998). Moreover, they almost exclusively germinate at higher temperatures (Patzelt & Pfadenhauer 1998), which can be interpreted as a selective adaptation to the delayed warming up of wetland soils (Grime et al. 1981). Full shading with more uniform temperatures at ground level, such as in tall grass stands, inhibits germination (Maas 1988).

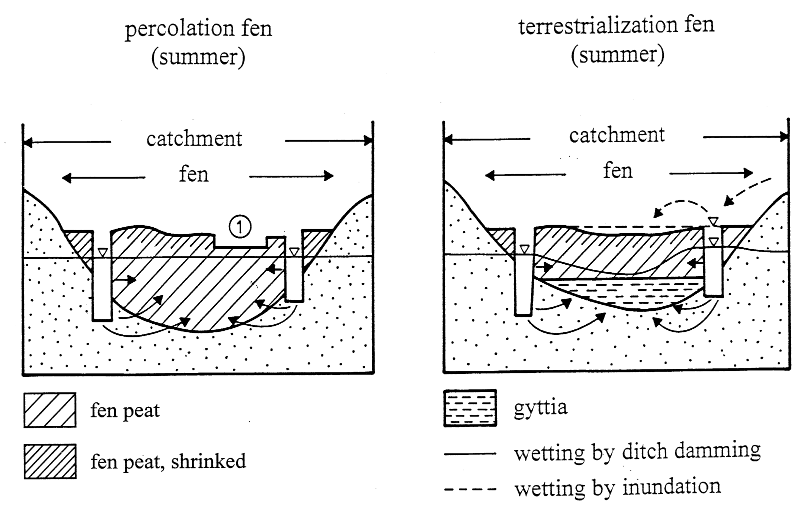

Fig. 4. Rewetting measures in Northern German fens (redrawn according to Hennings 1996, modified). 1 = top soil removal. Arrows indicate incoming water.

Impoverishment of the soil can also restrict successful establishment of target species when essential nutrients become in very short supply (Koerselman & Verhoeven 1995). A marked potassium deficiency, for instance, may occur after prolonged drainage of fen peat soils and also after continuous mowing without fertilization (van Duren et al. 1997a, b; Egloff 1986). Potassium deficiency favours grasses while inhibiting the development of *Leguminosae* seedlings and other herbs (Klapp 1971). If the K-level drops below 0.5% dry weight, fertilization with K is necessary to enable establishment of desired species, while (co-) limitation of phosphorus and nitrogen stimulates the establishment of many fen meadow species (Biewer 1997).

The most drastic impoverishment can be achieved by removal of the nutrient-rich topsoil. This measure is feasible only when the target species for restoration are present neither in the plant cover nor in the seed bank. In addition to the radical depletion of nutrients, undesirable competitive elements are removed, although they may redevelop from the seedbank when sod cutting was too shallow (van Diggelen et al. 1997). The underlying peat layer is often more porous and less strongly altered than the topsoil, and thus more suitable for the growth of wet meadow plants (Wild 1997). Sod stripping, however, also eliminates the protective cover of the vegetation for germination and seedling establishment. Addition of hay or the use of fleece could compensate this effect. Sod cutting is very costly, unless the fertile soil can be sold (Grootjans & van Diggelen 1998).

Keystone species

The fulfilment of a development plan can fail due to the lack of certain species which initiate or accelerate the desired development process. These species are key species for the relevant process; their significance for the success of a restoration is illustrated by the following example. In southern Germany a project was initiated to restore remnants of an industrially exploited peat area into a growing ombrogenous bog (Kendlmühlfilze, Chiemsee; see Pfadenhauer 1989). The intention was to create conditions which would facilitate the settlement of *Sphagnum* mosses (in particular *S. cuspidatum, S. magellanicum, S. capillifolium*), and thus the re-establishment of a kind of acrotelm. Analysis of macro-remains and the study of vegetation succession in old peat pits (Poschlod 1995) suggested that *Carex rostrata* appeared to be a key species in early stages of peat formation.

After rewetting of the milled peat areas, partly with calcareous groundwater, partly after modest phosphorus/potassium fertilization, this sedge was planted using rhizome segments. Under these site conditions, *Carex rostrata* formed an open vegetation within two years (Sliva1997). Newly established or planted *Sphagnum* shoots were scarce at first, but soon they developed into well-growing hummocks; between the young *Carex rostrata* shoots the *Sphagna* carpets rapidly reached a height of ca. 30 cm on the partly shaded sites. The *Carex* lawn enabled them to escape the effects of the water table fluctuations. On the other hand, on ecologically comparable sites without *Carex rostrata* the planted *Sphagnum* mosses died during the same period. Whether or not these *Sphagna* carpets will eventually form a hydrologically stabilizing acrotelm will be decided by coming generations of mire researchers. Nevertheless this example shows that introduction of key species can help to control a desired development in the beginning of restoration processes.

Seed sowing

The (re)introduction of species is sometimes used to boost the biodiversity of wet meadows. It has a very positive effect in many restoration projects that have been carried out during the last decades. The results are visible after a relatively short time, thus promoting acceptance of the projects and facilitating financial support. Target species may be introduced by planting individuals or by sowing seeds. The import of hay containing ripe seeds has proved particularly successful in fen meadow (*Molinion*) restoration (Patzelt et al. 1997; Biewer 1997). The hay originates from well developed reference areas. This technique has two advantages: First, the method is cheap and easy. The hay is harvested at a period when most species produce seeds (in case of pre-alpine fen meadows mostly in the middle of June); immediately after harvesting it is transported to the impoverished receiving area and then spread out in a thin layer. Second, autochthonous hay guarantees that only those ecotypes become established which are possibly adapted to the local climatic conditions. Commercial seed mixtures or seeds of unknown origin may contain less well adapted individuals.

However by no means all species of the donor areas can be transferred. The transfer rates lie between 40% (on nutrient-depleted meadows; Biewer 1997) and 70% (on areas with top soil removal; Patzelt et al. 1997). The hay does not contain seeds of species which set seed earlier or later in the year. Some species do not develop viable seeds or do not germinate under the new site conditions. Planting of rhizome segments or horticulturally pre-grown seedlings will be more suitable for such species.

Conclusions

Successful restoration of destroyed wetlands by an optimal combination of rewetting, nutrient depletion and re-introduction of species requires a thorough knowledge of key ecological processes. Some of these processes are well-known, but processes associated with restoration of highly degraded mires are still largely unknown. We know little about the speed and extent of peat formation under flooding conditions, nor on the species composition that eventually will emerge. It may well be that species that nowadays are exclusively found in anthropogenic wet meadows, will also establish in restored fens, since they used to be present in original mires. Furthermore, initially highly productive reed and sedge stands may eventually develop into low-productive small sedge communities, when a fen acrotelm is formed capable of nutrient fixation, and thus offering Red List species a niche without the need for human intervention.

The initiation and future peat development are long-term processes which may extent over a period of several centuries. Thus, restoration measures cannot be expected to prove successful in the short-term, i.e., in a foreseeable period of 10 to 20 yr, and not at all within the time of political terms of office. Destruction of wetland areas, therefore, cannot be justified by an idle notion of future restoration possibilities.

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Received 28 September 1998;
Revision received 24 March 1999;
Accepted 9 April 1999.